

Elastic Nd scattering at intermediate energies as a tool for probing the short-range deuteron structure

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A calculation of the deuteron polarization observables A_y^d , A_{yy} , A_{xx} , A_{xz} and the differential cross-section for elastic nucleon-deuteron scattering at incident deuteron energies 270 and 880 MeV in lab is presented. A comparison of the calculations with two different deuteron wave-functions derived from the Bonn-CD NN -potential model and the dressed bag quark model is carried out. A model-independent approach, based on an optical potential framework, is used in which a nucleon-nucleon T -matrix is assumed to be local and taken on the energy shell, but still depends on the internal nucleon momentum in a deuteron.

I. INTRODUCTION

The reaction of elastic nucleon-deuteron scattering is considered both by experimentalists and theoreticians as one of the clue tasks in few-nucleon physics. For three decades it has been served as a hope to obtain more information about the intermediate- and short-range NN interaction and as a probe of the deuteron structure at small distances (for a review, see Ref. [1]). During the last decade it is also studied with the purpose of testing of various three-nucleon forces (3NF) and particularly their spin-dependence [2, 3]. It is also of interest as a basic reaction to establish a polarimetry for vector-tensor mixed polarized beams.

To describe Nd elastic scattering below the pion production threshold different techniques have been applied [4, 5, 6, 7]. The momentum space Faddeev equations can now be solved with high accuracy for the most modern two- and three-nucleon forces. The 3NFs in such a calculations are of Fujita-Miyazawa [8, 9] or Tucson-Melbourne [10] type. It was found from these calculations that the differential cross section and the polarization observables are essentially insensitive to the choice of the two-nucleon interaction provided it is in agreement

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with NN elastic scattering data.

The next step is to go to the higher momentum transfer region and to explore this reaction above the NN inelastic threshold. But calculations at incident proton energies greater than 200 MeV in lab encounter with some nontrivial difficulties. The first problem is that up to now there is no reliable quantitative model for the NN -interaction above the inelastic threshold. All existing models that pretend to description of two-nucleon scattering up to 1 GeV do it only in semi-quantitative manner [11, 12]. The second problem is that it is no longer conventional three-body problem. Nucleon isobar and meson degrees of freedom start to play a significant role and disguise the effects from the short-range two-nucleon interaction [13]. And last but not least, there are purely computational difficulties in performing relativistic Faddeev calculations at higher energies [14, 15]. Hence, the existing theoretical frameworks of elastic Nd scattering at intermediate energies concern mainly to the very backward scattering angles where short-range behavior of a deuteron wave function (DWF) is, as expected, the most evident. The common framework at these energies is a multiple scattering formalism, where the two-body Nd amplitude is expanded in series of a NN T-matrix. In the absence of a reliable two-nucleon potential in the GeV region, the T-matrix is usually taken either on-energy-shell [16] or extrapolated off-shell in a model independent fashion [17]. So, the DWF contains the only information about the NN interaction in these models.

Now, there is a set of high quality nucleon-nucleon potentials, based mainly on a meson exchange picture, that describe deuteron properties and two-nucleon elastic scattering data perfectly below the pion production threshold [18, 19, 20]. With the inclusion of a 3NF, they also provide a good description for the 3N binding energies and the nucleon-deuteron differential cross section. The general feature of these models is an uniform depletion of the DWF at small internucleon distances.

In the last two decades, numerous attempts have been made to describe the intermediate and short-range NN interaction by methods of QCD [21, 22, 23, 24, 25]. The advantages of the quark models are that only a few physically meaningful parameters can be used to describe processes involving hadrons and a possibility to take the underlying symmetries of QCD directly into account. Most of these attempts focused only on elastic NN scattering at rather low energies and/or on low partial waves and are not suitable as input in few-body calculations. However, some of the features of a few-nucleon system, derived within

the frameworks, can be further explored and tested. Especially it concerns the short-range behavior of the deuteron and 3N bound states. One of the successful models based on six-quark ($6q$) symmetries is a dressed bag model (DBM) proposed recently [25, 26]. The essence of this model lies in different dynamics of the quark configurations $|s^4p^2[42]_x L = 0, 2\rangle$, $|s^3p^3[33]_x L = 1, 3\rangle$ and the most symmetric ones $|s^6[6]_x L = 0\rangle$, $|s^5p^1[51]_x L = 1\rangle$. Whereas the first two configurations have a cluster structure and are projected mainly on the NN channel, the third and fourth configurations have the structure of a quark bag with a large weight of the $\Delta\Delta$ and CC (hidden-color) states. As a result, the deuteron and 3N wave functions have a short-range node, which result from the orthogonality of the cluster wave function and the wave function of the $6q$ compound state. These $6q$ symmetry arguments are also the foundations for the Moscow NN -potential model [27, 28]. In the framework of the DBM, it turned out to be possible to fit very reasonably the NN phase shifts in 1S_0 and $^3S_1 - ^3D_1$ channels up to 1 GeV and the deuteron static properties as well. As to the 3N systems, this model could explain quantitatively all static properties of ^3He and ^3H ground states, including a precise parameter-free description of the Coulomb displacement energy of $^3\text{He} - ^3\text{H}$ and all the charge distributions in these nuclei [29, 30].

In this work, elastic Nd scattering is considered as a possible discriminative tool between calculations with two different kinds of a DWF. The first one is derived from the Bonn-CD NN potential [20] and diminishes uniformly with approaching the internucleon distance to zero. The second one is a result of the DBM [25] and develops a nodal behavior. The framework is based on an optical potential formalism. A multiple scattering expansion is used to derive the optical potential that comprises of the one-nucleon-exchange (ONE) mechanism, the single- and double-scattering terms. As shown by Faddeev calculations, at energies below about 200 MeV rescattering of higher order is very important, however around 300 MeV the first two terms in the expansion are sufficient to describe the total Nd cross section [31]. For the NN input, a model-independent approach is used in which the nucleon-nucleon T -matrix is assumed to be local and taken on-shell, but in contrast to the common impulse approximation it still depends on the internal nucleon momentum. Thus the two-nucleon amplitude cannot be factorized out of an integral and some kinematical off-shell effects are implicitly taken into account.

The deuteron vector and tensor analyzing powers and the differential cross section are calculated for two deuteron kinetic energies E_d in lab - 270 MeV and 880 MeV. At $E_d = 270$

MeV a comparison with precise data measured at RIKEN [32] is performed to validate the model. At this energy the difference between the calculations with the two kinds of a DWF is, as expected, not remarkable. The calculation at 880 MeV is performed in view of the recent experiment at JINR [33], in which the deuteron polarization observables were measured in the region of the so called "cross-section minimum" ($\theta_{\text{cm}} = 70 - 140^\circ$) where both vector and tensor analyzing powers can have large values.

The structure of the paper is as follows. In Section 2, the formalism of the optical potential and multiple series expansion is briefly given. The approximation to the fully off-shell NN T-matrix is developed and the Nd scattering amplitude is defined. Section 3 is devoted to results of the calculation and their discussion. Conclusion summarizes the content of the work.

II. THEORETICAL FRAMEWORK

The basic equations for a three-body system in quantum physics are Faddeev equations which can be written in the operator form [1]:

$$U = PG_0^{-1} + PTG_0U, \quad (1)$$

where $U = U_{\mu'_d\mu'_N, \mu_d\mu_N}(\vec{q}', \vec{q})$ is an amplitude of elastic Nd -scattering, \vec{q} (\vec{q}') – initial (final) relative momentum in the nucleon-deuteron c.m., μ_d, μ_N are spin quantum numbers, T – NN scattering T-matrix, $G_0 = (E - H_0 + i\epsilon)^{-1}$ is a free propagator of the $3N$ system and $P \equiv P_{12}P_{23} + P_{13}P_{23}$ stands for a permutation operator that takes into account the property of identity of three nucleons.

One can rewrite (1) in the form that is more appropriate for calculations at higher energies where a multiple scattering expansion is justified [34]:

$$U = V_{\text{opt}} + V_{\text{opt}}G_dU. \quad (2)$$

This is an optical potential framework and V_{opt} is a nucleon-deuteron optical potential:

$$V_{\text{opt}} = PG_0^{-1} + PT_cG_0V_{\text{opt}}. \quad (3)$$

Here T_c is a NN T-matrix without the deuteron pole term and G_d is a deuteron contribution in the spectral decomposition of the two-body Hamiltonian.

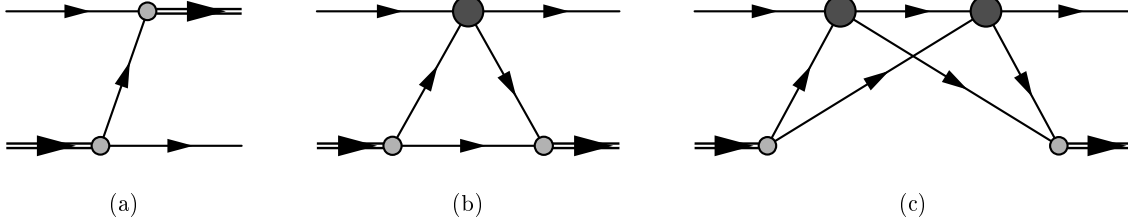


FIG. 1: The Nd optical potential up to the second order in the multiple series expansion:

(a) – one-nucleon exchange, (b) – single scattering, (c) – double scattering; dark-filled circles represent the NN T-matrix and grey-filled – deuteron wave function.

Although, Eq. (2) seems quite simple and represents a common two-body scattering equation, the derivation of the optical potential from Eq. (3) is as difficult as solving the Faddeev equations themselves. However, one can employ a multiple scattering expansion of V_{opt} , keeping a possibility to include in V_{opt} some additional terms originated, for example, due to a 3NF. At higher energies only a few terms in this expansion may be sufficient to describe observables [31]:

$$V_{\text{opt}} = PG_0^{-1} + PT_cP + PT_cG_0PT_cP + \dots \quad (4)$$

In Fig. 1 a schematic representation for the optical potential (up to the second order in series expansion) is shown. The first diagram (Fig. 1(a)) is a usual one-nucleon exchange mechanism, the second graph (Fig. 1(b)) is a so called triangle diagram and represents the single-scattering process. And Fig. 1(c) represents the double-scattering which takes into account the break up channel and the double-charge exchange mechanism.

If to define an initial state as $|i\rangle \equiv |\vec{q}; \mu_d \mu_N\rangle_{1(23)}$, where a proton 1 is in continuum and a proton 2 and a neutron 3 are bound in the deuteron, then (4) can be written in the matrix form:

$$\begin{aligned} \langle f|V_{\text{opt}}|i\rangle = & {}_{2(31)}\langle f|G_0^{-1}|i\rangle + {}_{1(23)}\langle f|T_c^{2(31)}|i\rangle + {}_{1(23)}\langle f|\tilde{T}_c|i\rangle + \\ & {}_{1(23)}\langle f|\tilde{T}_cG_0T_c^{2(31)}|i\rangle + {}_{1(23)}\langle f|T_c^{2(31)}G_0\tilde{T}_c|i\rangle + {}_{2(31)}\langle f|T_c^{1(23)}G_0T_c^{2(31)}|i\rangle. \end{aligned} \quad (5)$$

Here,

$${}_{1(23)}\langle f|\tilde{T}_c \equiv {}_{1(23)}\langle f|T_c^{3(12)} + {}_{2(31)}\langle f|T_c^{3(12)}$$

is an antisymmetrized proton-proton T-matrix and $T_c^{k(ij)}$ means that the interaction is occurred between the particles i and j whereas the particle k is a spectator.

The one-nucleon exchange contribution is written in a usual way:

$${}_{2(31)}\langle f|G_0^{-1}|i\rangle = \left[\sqrt{q^2 + M_N^2} + \sqrt{4q^2 \cos^2 \frac{\theta}{2} + M_N^2} - \sqrt{q^2 + M_d^2} \right] \Psi_{13}^\dagger \left(\vec{q} + \frac{1}{2}\vec{q}' \right) \Psi_{23} \left(\vec{q}' + \frac{1}{2}\vec{q} \right).$$

Here, a complicated notation related to a summation over spin and orbital quantum numbers is omitted. Ψ_{ij} is a wave function of the deuteron composed of nucleons i and j , θ is a scattering angle and

$$q' = q = \left(\frac{E_d M_N^2 (E_d + 2M_d)}{(M_N + M_d)^2 + 2M_N E_d} \right)^{1/2},$$

where E_d is a kinetic energy of the deuteron in lab.

To evaluate a single scattering diagram, one must implement an integration over the internal momentum of nucleons in the deuteron. To do this, a knowledge about the fully off-shell behavior of the NN T-matrix is required:

$${}_{1(23)}\langle f|T_c|i\rangle = \int \frac{d^3p}{(2\pi)^3} \Psi_{23}^\dagger \left(\vec{p} + \frac{1}{4}\vec{k} \right) T_c \left(\vec{q}', \vec{p} - \frac{3}{4}\vec{q}' + \frac{1}{4}\vec{q}; \vec{q}, \vec{p} - \frac{3}{4}\vec{q} + \frac{1}{4}\vec{q}' \right) \Psi_{23} \left(\vec{p} - \frac{1}{4}\vec{k} \right), \quad (6)$$

here $k = \vec{q} - \vec{q}'$ is a transferred momentum.

However, the absence of a high quality NN interaction model above the inelastic threshold at the present moment forces anyone to make some approximate evaluation of the integral, proceeding from the assumption of either off-shell behavior of somehow parameterized T-matrix or taking only its on-shell value. The common approach of twenty years old calculations is an optimal impulse approximation [35, 36] in which the internal momentum in the T-matrix is put to zero in (6) that permits the T-matrix to be shifted outside the integral and the remaining integration produces the deuteron form factor. In this approximation the leading order corrections due to Fermi motion is vanished provided that the NN amplitude is spin independent and local. Thus the variation of the NN T-matrix with momentum \vec{p} is compensated to leading order in \vec{p}/M_N by appropriate choice of the energy parameter upon which the T-matrix depends. The condition on the energy is that the NN T-matrix be on-shell when evaluated at $\vec{p} = 0$ in Eq. (6). However, this approximation misses some vital momentum dependency in the T-matrix and is suitable only for scattering on a heavy nucleus where the recoil is not significant.

In this work, the T-matrix is put on-shell in a way that minimizes the off-shell corrections. Firstly, the NN T-matrix should be transferred to the two-nucleon c.m. frame, where it is

usually defined. By means of the Lorentz transformation $\mathcal{L}_\nu^\mu(\vec{P}_{\text{cm}})$, one has:

$$T_c \left(\vec{q}', \vec{p} - \frac{3}{4}\vec{q}' + \frac{1}{4}\vec{q}; \vec{q}, \vec{p} - \frac{3}{4}\vec{q} + \frac{1}{4}\vec{q}' \right) = \Lambda(\mathcal{L}) T_c^{\text{cm}}(\vec{Q}', \vec{Q}) \Lambda^{-1}(\mathcal{L}), \quad (7)$$

where $\vec{Q}' = (\mathcal{L}^{-1}[\vec{q}'] - \mathcal{L}^{-1}[\vec{p} - \frac{3}{4}\vec{q}' + \frac{1}{4}\vec{q}]) / 2$ and $\vec{Q} = (\mathcal{L}^{-1}[\vec{q}] - \mathcal{L}^{-1}[\vec{p} - \frac{3}{4}\vec{q} + \frac{1}{4}\vec{q}']) / 2$ are final and initial two-nucleon relative momenta in NN c.m. and Λ is a transition operator that includes the boost and the Wigner spin rotations of the T-matrix; $\vec{P}_{\text{cm}} = \vec{p} + \frac{1}{4}\vec{q}' + \frac{1}{4}\vec{q}$ - c.m. momentum of the two-nucleon system.

If the T-matrix is not strongly energy-dependent and essentially local, then it depends on two variables - transferred momentum $(\vec{Q}' - \vec{Q})^2$ for the direct NN -interaction and $(\vec{Q}' + \vec{Q})^2$ in case of the exchange mechanism. Then one can introduce two new variables \tilde{Q} and $\tilde{\theta}$ that correspond to the on-shell relative momentum and scattering angle and define them as follows:

$$|\vec{Q}' - \vec{Q}| = 2\tilde{Q} \sin(\tilde{\theta}/2), \quad |\vec{Q}' + \vec{Q}| = 2\tilde{Q} \cos(\tilde{\theta}/2). \quad (8)$$

Thus, the T-matrix T_c^{cm} is taken to be on-mass shell and calculated at the effective two-nucleon energy in lab

$$E_{\text{eff}} = \frac{2\tilde{Q}^2}{M_N} = \frac{\vec{Q}'^2 + \vec{Q}^2}{M_N}. \quad (9)$$

Thus, although the NN T-matrix is evaluated on-shell, it still contains some off-shell information, since the effective energy E_{eff} and the scattering angle $\tilde{\theta}$ depends on the off-shell momenta \vec{Q}' and \vec{Q} . Particularly, the effective energy depends on the internal nucleon momentum \vec{p} , and therefore the T-matrix cannot be driven outside the integral in Eq. (6). Moreover, some off-shell dependency is present on a relativistic level in the operator Λ when the transformation of the T-matrix from the NN c.m. frame to the nucleon-deuteron c.m. frame is performed according to Eq. (7). In the relativistic case, this approximation corresponds to the situation when the T-matrix depends only on the two kinematical invariants - t and u , and its evaluation is performed via imposing the on-shell condition on the squared total energy $s = 4M_N^2 - u - t$.

For the double scattering term one should evaluate a six-dimensional integral over the internal momentum in the deuteron and the intermediate momentum of the scattered nu-

cleon:

$$\begin{aligned}
& {}_{1(23)}\langle f|T_2G_0T_1|i\rangle = \\
& \int \frac{d^3\mathbf{p}}{(2\pi)^3} \frac{d^3\mathbf{q}''}{(2\pi)^3} \Psi_{23}^\dagger\left(\vec{p} + \frac{\vec{q}''}{2}\right) T_2\left(\vec{q}', \vec{p} + \frac{1}{2}(\vec{q}'' - \vec{q}'); \vec{q}'' + \frac{1}{2}(\vec{q} + \vec{q}'), \vec{p} - \frac{1}{2}(\vec{q} + \vec{q}'')\right) G_0 \\
& \times T_1\left(\vec{q}'' + \frac{1}{2}(\vec{q} + \vec{q}'), -\vec{p} - \frac{1}{2}(\vec{q}' + \vec{q}''); \vec{q}, -\vec{p} - \frac{1}{2}(\vec{q} - \vec{q}'')\right) \Psi_{23}\left(\vec{p} - \frac{\vec{q}''}{2}\right), \quad (10)
\end{aligned}$$

The NN T-matrices in (10) are approximated in the same manner as for single-scattering according to Eqs. (7)-(9). The Green function G_0 is taken in a nonrelativistic form to simplify the evaluation of the pole part of the integral:

$$G_0^{-1} = \frac{q^2}{2M_N} + \frac{q^2}{2M_d} - \frac{(\vec{q}'' + (\vec{q} + \vec{q}')/2)^2}{2M_N} - \frac{(\vec{p} - (\vec{q} + \vec{q}'')/2)^2}{2M_N} - \frac{(\vec{p} + (\vec{q}' + \vec{q}'')/2)^2}{2M_N}. \quad (11)$$

Assuming here $M_d = 2M_N$, one can rewrite it as follows

$$G_0^{-1} = \frac{(q^2 - \vec{q}\vec{q}')/2 - R^2}{2M_N}, \quad (12)$$

where

$$R^2 \equiv \frac{3}{2}q''^2 + 2p^2 + \frac{3}{2}\vec{q}''(\vec{q} + \vec{q}') + \vec{p}(\vec{q}' - \vec{q}). \quad (13)$$

Then, redefine the variables of integration and instead of the variables $|\vec{q}''|$ and $|\vec{p}|$ introduce two new variables R and α as

$$|\vec{q}''| = \sqrt{\frac{2}{3}}R \cosh \beta \cos \alpha, \quad (14)$$

$$|\vec{p}| = \sqrt{\frac{1}{2}}R \cosh \beta \sin \alpha. \quad (15)$$

The expression for β can be found by substituting these definitions in Eq. (13). Thus, the evaluation of the pole part of the integral (10) is straightforward. Here, the both the pole and the principal parts of integration in the double-scattering term is taken into account. The evaluation of the integrals is performed by means of the Monte-Carlo simulations, dividing the integration domain on several parts to minimize numerical errors.

The scattering equation (2), which is here a relativistic Lippmann-Schwinger equation, is solved in helicity basis employing a K -matrix approximation, i.e. only the pole part of the two-body propagator G_d is remained thus all terms in the equation contain only on-shell

information about the optical potential and the scattering amplitude:

$$\begin{aligned} \langle \lambda'_d \lambda'_N | U^J(q', q) | \lambda_d \lambda_N \rangle &= \langle \lambda'_d \lambda'_N | V_{\text{opt}}^J(q', q) | \lambda_d \lambda_N \rangle - i \frac{A(q, q)}{q} \langle \lambda'_d \lambda'_N | V_{\text{opt}}^J(q', q) U^J(q, q) | \lambda_d \lambda_N \rangle + \\ &\frac{2}{\pi} \mathcal{P} \int \frac{dq''}{q^2 - q''^2} \left(\langle \lambda'_d \lambda'_N | V_{\text{opt}}^J(q', q'') U^J(q'', q) | \lambda_d \lambda_N \rangle A(q'', q) - \langle \lambda'_d \lambda'_N | V_{\text{opt}}^J(q', q) U^J(q, q) | \lambda_d \lambda_N \rangle A(q, q) \right), \end{aligned} \quad (16)$$

where the kinematical factor is

$$A(q'', q) = q''^2 \frac{(E_q + E_{q''})((E_q^2 + E_{q''}^2)/2 - q^2 - q''^2 - M_N^2 - M_d^2)}{E_q^2 + E_{q''}^2},$$

and $E_q = \sqrt{q^2 + M_N^2} + \sqrt{q^2 + M_d^2}$ is a total energy.

Then for the Nd scattering amplitude in spin space one has (the incident particle is going along the z -axis):

$$\begin{aligned} \langle \mu'_d \mu'_N | U(q, \theta) | \mu'_d \mu'_N \rangle &= 4\pi \sum_J \sum_{\lambda'_d, \lambda'_N} (-1)^{\lambda'_d - \mu_d} (2J + 1) d_{\mu'_N, \lambda'_N}^{1/2*}(\theta) d_{\mu'_d, -\lambda'_d}^{1*}(\theta) \\ &\times d_{\lambda'_N - \lambda'_d, \mu_N + \mu_d}^J(\theta) \langle \lambda'_d \lambda'_N | U^J(q, q) | -\mu_d \mu_N \rangle, \end{aligned} \quad (17)$$

where J is a total angular momentum.

III. RESULTS AND DISCUSSION

The calculation of the deuteron polarization observables $A_y^d, A_{xx}, A_{yy}, A_{xz}$ and the differential cross section is performed with two different deuteron wave functions. The first one is a wave function derived in the meson-exchange Bonn-CD model [20]. The general trait of wave functions of this kind, derived from the most modern NN potentials, is their uniform behavior at small distances. The other possible choice is a wave function with a nodal behavior. This node corresponds to the so-called forbidden state in a NN system as a consequence of the six-quark dynamics and the fact that the mostly symmetric six-quark state $|s^6\rangle$ has a small NN component [37]. As one of the representatives of such a wave functions with nodal behavior can serve a wave function of the DBM [25], which has a node in the 3S_1 wave at a distance of $\simeq 0.6$ fm.

Although the NN T-matrices in the Nd amplitude are taken on-shell, they still depend on the off-shell momenta, particularly on the internal nucleon momentum in the deuteron.

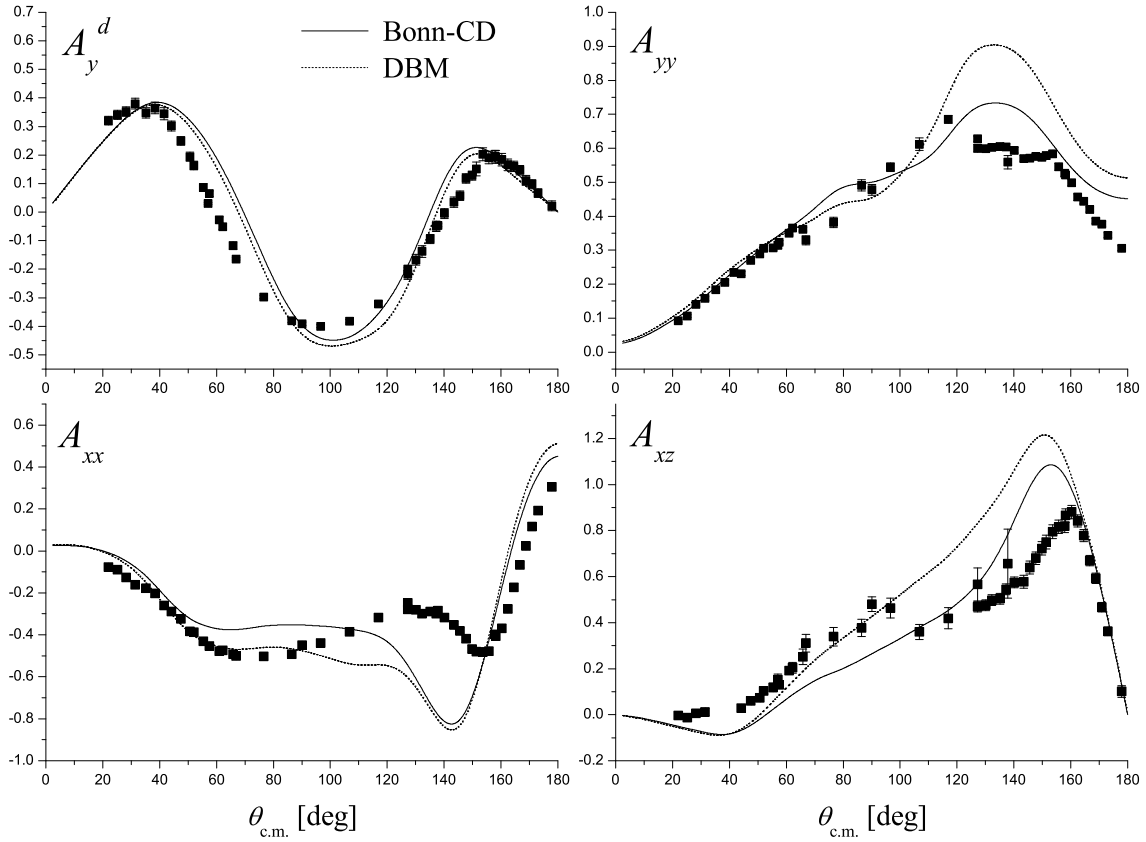


FIG. 2: Deuteron vector and tensor polarization observables at the energy $E_d = 270$ MeV in lab. The solid and dashed curves are calculations with the DWF derived in the Bonn-CD model and the DBM respectively. The experimental data are taken from Ref. [32].

This dependency is hidden in a value of the effective on-shell energy and NN scattering angle. The integration on the internal momentum means that the knowledge of the T -matrix at a large energy interval is required. The NN T -matrices are calculated using the recent partial wave analysis SP07 [38] which extends to 3 GeV for pp scattering and 1.3 GeV for np scattering. All partial waves up to the total angular momentum $J_{NN} = 7$ are taken.

In Figs. 2 and 3(a) the calculations of the observables at the deuteron energy $E_d = 270$ MeV are shown for the two different deuteron wave functions. The experimental data are taken from Ref. [32]. The convergent results in the sum (17) are obtained at $J = 25/2$. The full curve is a calculation with the Bonn-CD DWF, and the dashed curve is a calculation

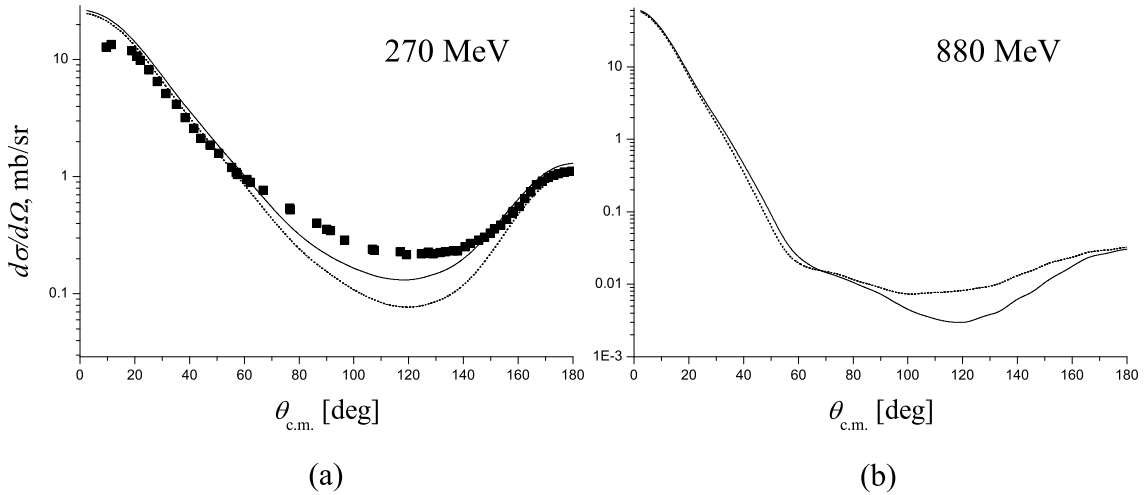


FIG. 3: The differential cross section at energies $E_d = 270$ and 880 MeV. The definition of the curves is the same as in Fig. 2.

with the DWF from the dressed-bag model. As one can see, the two calculations do not differ significantly from each other. The difference between them is of the same order as a disagreement with the experimental data and is seemed to be caused by approximate treatment of the off-shell effects in the NN T-matrix. Whereas for the Bonn-CD calculation the assumption of locality of the NN potential and amplitude may be a good approximation, the NN potential in the DBM is highly nonlocal and energy dependent, thus some off-shell effects from the T -matrix of the DBM may cancellate the effects from the nodal behavior of the DWF. As for the differential cross-section, the calculations practically coincide with that derived from a solution of the Faddeev equations without a 3NF. The lack of the cross-section at intermediate scattering angles is a common feature of such a calculations. Thus the higher rescattering terms in the Nd optical potential and dynamical off-shell effects are not significant for the cross section at this energy. The deuteron polarization observables are also in a good agreement with the experiment. It should be noted here, that even the Faddeev calculations that include a 3NF are only partially successful in a description of the polarization data.

The convergence of the calculations for forthcoming experimental data at $E_d = 880$ MeV

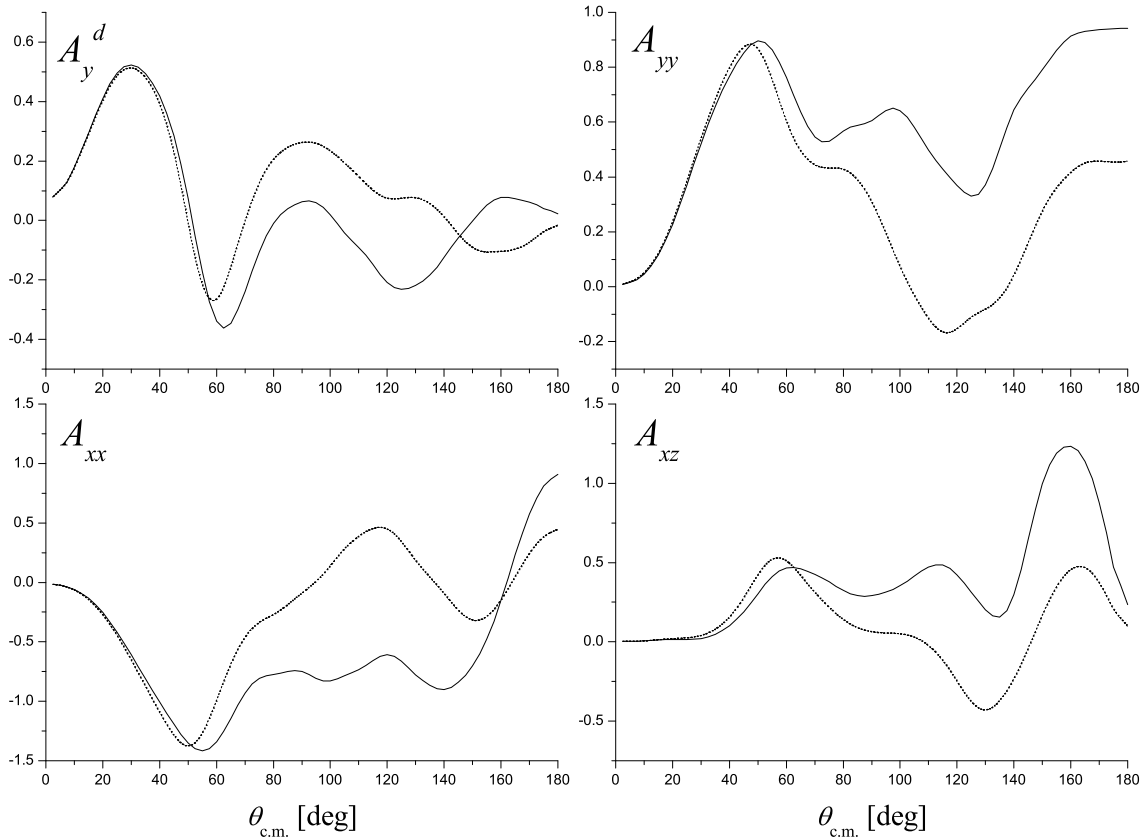


FIG. 4: The same as in Fig. 2, but for $E_d = 880$ MeV.

[33] is achieved at the total angular momentum $J = 39/2$. This is a quite large value, hence the Faddeev calculations are very difficult to solve at higher energies in the partial wave basis. As can be seen from Fig. 4, the differences between the curves derived from the two DWFs are remarkable. Only for small scattering angles $\theta \leq 50^\circ$, where the transferred momentum is not large, the two calculations give almost the same results. It is interesting to note, that at very backward scattering the differential cross-section is mostly insensitive to the kind of a DFW and the maximum difference becomes apparent in the cross-section minimum region (see Fig. 3(b)). However, to make quantitative calculations at these energies the 3NF contribution due to the excitation of the Δ -isobar must be taken into account. This contribution is the most likely mechanism to render the cross-section fall-off at backward angles [13]. Furthermore in the dressed-bag model, 3.6% to the DWF contributes from

the 6 q -bag which at this scattering energies can take a large transferred momentum. So, the 3NF, originated from the scattering of a nucleon on this quark bag, can also provide a significant contribution at backward scattering angles. Anyway, such a 3NF provides a large amount of the ${}^3\text{H}$ and ${}^3\text{He}$ bound energies [29].

IV. CONCLUSIONS

A calculation of the deuteron polarization observables A_y^d , A_{yy} , A_{xx} and A_{xz} and the differential cross section in an optical potential formalism for elastic nucleon-deuteron scattering at incident deuteron energies $E_d = 270$ and 880 MeV was presented. Under the investigation was the calculations with two different deuteron wave functions derived from the Bonn-CD NN -potential model and the QCD-motivated dressed bag model. For the NN input, the model independent approach was employed, in which the nucleon-nucleon T-matrix was taken to be on-shell in a way that some kinematical off-shell effects were incorporated in the definitions of the effective NN scattering angle and energy. It was found that the differential cross section is not affected by the higher rescattering contributions and the off-shell effects in the NN amplitude have a minor influence on this observable. At the energy $E_d = 880$ MeV, large differences in the observables calculated from the two DWFs were observed in the cross-section minimum region both for the analyzing powers and the differential cross section. However at the backward scattering angles, the differential cross section was shown to be mostly insensitive to the short-range deuteron structure.

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